Decreasing Vibration in the Advanced Photon Source Cooling Water System

Lindsay Frerichs
Office of Science, Student Research Program
Iowa State University
Argonne National Laboratory
Argonne, Illinois

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Participant: ______________________________

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Research Advisor: ______________________________

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Abstract

Decreasing Vibration in the Advanced Photon Source cooling system. LINDSAY FRERICHS (Iowa State University, Ames, IA, 50011) Gene Swetin (Argonne National Laboratory, Argonne, Illinois, 60439).

Hydraulic surging can cause physical damage and detrimental vibrations to a piping system. Rapid changes in velocity and direction release kinetic energy in the form of pressure spikes. Uncontrolled these pressure spikes oscillate along the pipe creating vibration until friction dissipates them. These vibrations are being felt in the Advanced Photon Source (APS) cooling system. Four experimental systems were designed to determine what is the most cost effective way to decrease the amount of vibration in the APS cooling system. The first system tested was the current cooling system configuration using a balancing valve to throttle the flow. The second experiment replaced the balancing valve with a balancing coil, and the third and fourth systems introduced a surge suppression device along with a balancing valve. The surge suppressor is designed specifically for absorbing pressure spikes and eliminating vibration in the flow. The difference between the third and fourth systems was the type of connections used; one used hose connections while the other used hard tubing. These four systems were tested at five flow rates; one, two, three, six and nine gallons per minute (GPM), using a dynamic signal analyzer. The analyzer showed the amount of displacement in meters root mean squared (mrms) caused by vibration at frequencies of zero to 60 Hertz (Hz). The surge suppressor worked extremely well, decreasing the amount of flow to just above the amount of background vibration. However, the suppressors are expensive. A less costly way of reducing vibration is to replace the balancing valve with a balancing coil. This creates less vibration then the valve, but does not work as well as the surge suppressor. The flow rate could also be reduced. Further research may focus on comparing different brands of surge suppressors.

Introduction

Hydraulic surging or “water hammer” as it is commonly called can cause damage to any piping system. It is the result of a rapid change in velocity or direction of the flowing liquid [1]. When the fluid is put into motion kinetic energy is added to it. The kinetic energy is seen as pressure and is carried in the fluid until it dissipates from friction. When the fluid suddenly encounters a change in velocity or direction, the kinetic energy is released as a pressure spike [2]. The intensity of the pressure spike is directly proportional to the speed of the flow before the change in velocity [3]. The pressure spike occurs because fluids are not compressible. They transfer the shock rather than absorb it, allowing the wave to travel the length of the pipe and then reverse, oscillating back and forth until friction dissipates it. Without control of the fluid these spikes can destroy pumps, piping valves, meters and in-line instrumentation. They can also cause detrimental vibrations [2].

The cooling system at the Advanced Photon Source (APS) has not received damage to any of its equipment from hydraulic surging, but it has experienced the detrimental vibrations. The vibrations in the cooling system are produced from two primary sources the centrifugal pumps and the flow in the pipeline. The pumps have a five-vane impeller that rotates at 3600 revolutions per minute, slapping the water and changing its velocity. The water also flows through elbows, tees, fittings, and flow meters. As it flows through these devices it changes velocity and direction, releasing a pressure spike [4]. Sound is also a minor cause of vibration, most of which is caused by the humming of the large centrifugal pumps [5].

The users of the Advanced Photon Source are feeling the vibrations in the cooling system in their experiments. Many of them are doing extremely sensitive research, and even the minutest vibrations can lessen the precision of their experiment. The users have inquired about a possibility to reduce vibration due to the cooling water system.

There are specific devices designed and manufactured to reduce hydraulic surging. However, APS has never used them before in the cooling system. Our research, will involve testing the current cooling system, along with other experimental systems including the surge suppression device. The data will be compared to determine which system has the least amount of vibration associated with it. Our data will then be available to users in order for them to evaluate the most cost efficient way of reducing vibration to their particular experimental arrangement.

Materials and Methods

Four experimental systems were designed and tested to determine which led to the least amount of vibration. The systems were built one at a time and connected to the water-cooling system that feeds the APS Experiment Hall. This cooling system is identical to the one used to cool the storage ring and the user hutches. The cooling system has a maximum flow rate of nine gallons per minute (GPM), and each system was tested at approximately: one, two, three, six, and nine GPM.

For all of the experiments water flowed from the supply header through the absorber. The absorber used in our systems is not the exact type of equipment that the users utilize, but is being used to simulate their vibrating equipment. Each user has different types of equipment in their hutch, and our experiment would have to be performed specifically for each user if their exact equipment was to be used. Instead, we are assuming that each piece of their equipment will act similarly to our absorber under the same conditions. A piece of soft rubber was also placed under the absorber to keep the table from dampening its vibrations.

After flowing through the absorber, the water traveled through two flow meters located in the return line, a maximum 20 GPM V-Cone type flow meter with Yokogawa differential pressure transmitter, and a maximum six GPM orifice plate flow meter, also with Yokogawa differential pressure transmitter calibrated for flow indication. Two flow meters needed to be used because the V-Cone cannot accurately read flow rates of two GPM or below, and the orifice plate cannot read above six GPM. Therefore, the orifice plate flow meter was used to take the one, two, three and six GPM readings, while the V-Cone flow meter was used to take the nine GPM reading. The orifice plate, however, had to be removed from the line when performing the nine GPM test, because it restricted the amount of flow in the system below nine GPM.

The first experiment tested (see figure 1) had a balancing valve in the line, in addition to the absorber and the flow meters. It was used to throttle the flow to obtain the desired flow rate. This is the standard setup currently used in the APS cooling system. Theoretically, the throttling causes more vibration because of the pressure change across the valve. This system was our base for comparison.

The second experiment (see figure 2) replaced the balancing valve, with a balancing coil. The coil lengths and sizes were calculated using the pressure drop across the balancing valve in the first system, and then adjusted using an educated guess and check system to obtain the desired flow rate. The balancing coil eliminates the need for throttling, and theoretically should eliminate a portion of the vibration.

The next two experiments (see figures 3&4) used a surge suppressor in addition to a balancing valve with either hose or tube connections. The surge suppressor is specifically designed to reduce hydraulic surge and was purchased from CoorsTek.

The surge suppressor was placed as close to the equipment being cooled as possible and is designed with a bladder to absorb the pulsing that causes vibration. Compressed nitrogen gas was introduced into the chamber of the suppressor at 85 percent of its operating pressure. The gas was then trapped by an elastomeric bladder, which prevents contact between the water and nitrogen gas. When a pulse or pressure spike was created, that caused vibration; the fluid entered the chamber of the suppressor and displaced the bladder, which compressed the gas and absorbed the shock. As the liquid pressure decreased, the gas expanded pushing fluid back into the line (see Figure 5) [1].

All of the experimental systems were tested using a DOS based HP 35670A portable; two or four channel Dynamic Signal Analyzer from Hewlett Packard. Two sensors were connected to the analyzer; one was placed on the table, the other on the absorber. The sensors must remain undisturbed for at least a half an hour between the time they are placed on the equipment and the time readings are taken. The sensors sit in a viscous fluid and must be allowed to settle out; otherwise they will give a false reading in the shape of a ski-slope. They were held in place by magnets on the sensors. The analyzer took ten 30 second readings simultaneously for the two sensors and averaged them together to display the final readings. The time averaging was performed to extract repetitive signals out of the noise. The sensors are extremely sensitive and can be affected by outside influences such as forklifts or loud talking which can also cause false readings. If this occurred a new test was performed. The analyzer measured displacement in meters root-mean square (mrms) at frequencies ranging from zero Hertz (Hz) to 60 Hz. The data collected was saved on standard floppy disks and loaded onto a PC, where Excel was used to open and analyze it [6].

Results

Figure 6 shows the results of the vibration test with the balancing valve alone at all of the tested flow rates. This is the current setup in the APS cooling system, so this is the amount of vibration that the users are currently experiencing in their equipment. From the figure two, three and six GPM flow rates show a larger amount of vibration then the one or nine GPM flow rates. The three and six GPM flow rates created almost equal amounts of vibration, showing the largest amounts of vibration in the system. Three GPM is also the current flow rate for the cooling water system.

Figure 7 displays the results of the vibration test with a balancing coil instead of the balancing valve. In this test, three GPM had noticeably more amounts of vibration then any other flow rate, although the six GPM test also showed large amounts of vibration. However, figure 8 shows that the setup with the balancing coil created less vibration then the balancing valve system at three GPM, but not significantly.

Figure 9 displays the data from the setup combining a surge suppressor and balancing valve with hose connections at all of the tested flow rates. With this test the three GPM flow rate now falls to the average amount of vibration, while nine GPM creates the most vibration. Figure 10 demonstrates the differences between the three experimental systems at three GPM, and shows that the surge suppressor really does work. It substantially lowers the amount of vibration in the system.

Displayed in figure 11 is the effect of using tube connections with the surge suppressor and balancing valve instead of hose at three GPM. At low frequencies the amount of vibration is approximately the same for both systems. At high frequencies, however, the tubing creates more vibration then the hose.

Discussion and Conclusion

As expected, the balancing valve system created the largest amount of vibration. Two factors contributed to this, the throttling of the balancing valve along with the flow velocity. The one and nine GPM flow rate tests had the least amount vibrations. Even though the one GPM test had the most throttling it had a very low flow velocity. In the nine GPM test the valve was wide open, so even though it had a high flow velocity there was no throttling, which led to very little vibration. The two, three, and six GPM flow rates all had larger amounts of throttling along with higher flow velocities. These two things compounded on each other to raise the amount of vibration in the system. The three GPM test seemed to be at the worst point in the spectrum for this effect.

Replacing the balancing valve with a balancing coil decreased the amount of vibration in the system. In this test the throttling was eliminated so the amount of vibration caused by it was lost. The flow velocity, however, was still a factor and can be seen in the data (see figure 7). The high flow velocities of the three and six GPM flow rates combined with the transitions in the line between the ½" tube supply line and the coil of hose created a fair amount of vibration. However, it was still less then the amount of vibration created at these flow rates by the balancing valve (see figure 8).

Adding the surge suppressor with the balancing valve, substantially decreased the amount of vibration in the system. With the suppressor all of the flow rates tested created roughly the same amount of vibration (see figure 9), which was just slightly above the amount background vibration. When adding the surge suppressor it does not matter if a balancing valve or coil is used since it is located before the surge suppressor, the suppressor eliminates any vibration caused by them, so either can be used. The hose connections in the system need to be restrained, because there is a large difference in the amount of vibration caused by the hose when it was restrained and when it was not. Due to this difference, we also tested the suppressor with tube connections to see if the more stable tube would create less vibration. The amount of vibration was relatively the same in the two systems (see figure 11), except at high frequencies where the vibration was worse when tube connections were used. Because the tubing made very little difference in the amount of vibration created and hose is easier to work with, the more logical system to utilize is the hose connections system.

Although the surge suppressor works extremely well it is also expensive. One suppressor costs roughly 3,000 dollars and may not be the most cost efficient solution for all of the APS users. A no cost way to lower the amount of vibration in the system slightly is to lower the flow rate in the system. If the vibration needs to be decreased by a larger amount, a low cost solution is to use a balancing coil instead of a balancing valve. The flow rate could also be reduced. If a dramatic decrease in vibration is needed a surge suppressor could be used, but at a much higher cost. With this system any flow rate could be utilized, the suppressor eliminates almost all of the vibration caused by flow velocity.

Our research presents a number of possible solutions to the users for decreasing the amount of vibration in the water-cooling system to their hutches. It allows the users to evaluate the most cost efficient way of reducing vibration in the cooling system for their particular research needs. Further research may be performed comparing the performance of different brands of surge suppressors.

Acknowledgements

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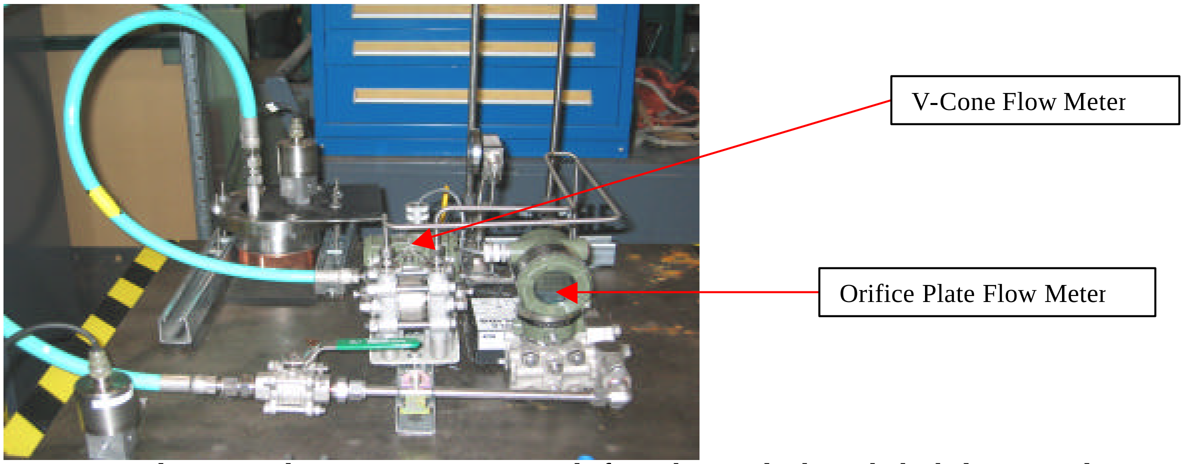

Figure 1: Balancing Valve System. Water travels from the supply through the balancing valve to the absorber, where the reading is taken.

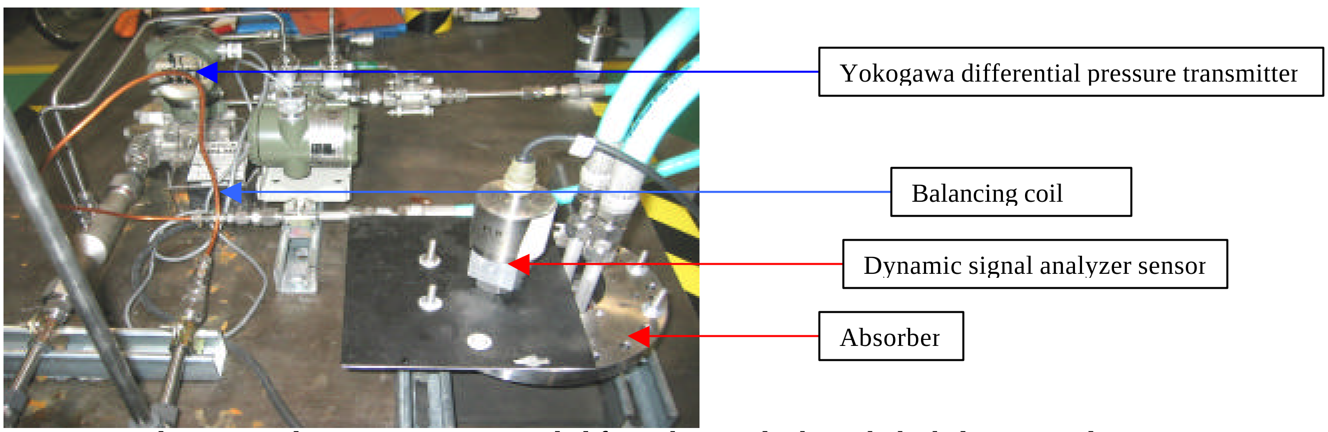

Figure 2: Balancing Coil System. Water traveled from the supply through the balancing coil to the absorber, where the vibration reading is taken.

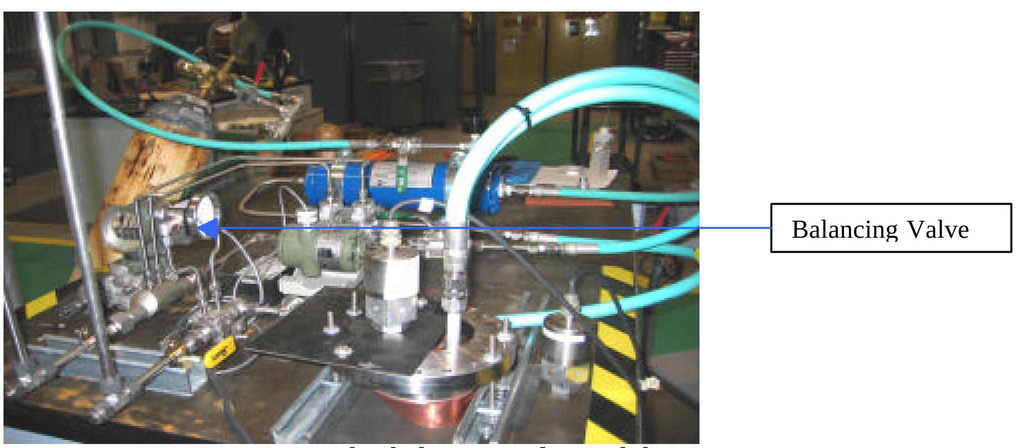

Figure 3: Surge suppressor plus balancing valve with hose connections system. Water flows from the supply through the valve to the surge suppressor, then from the suppressor to the absorber where the reading is taken.

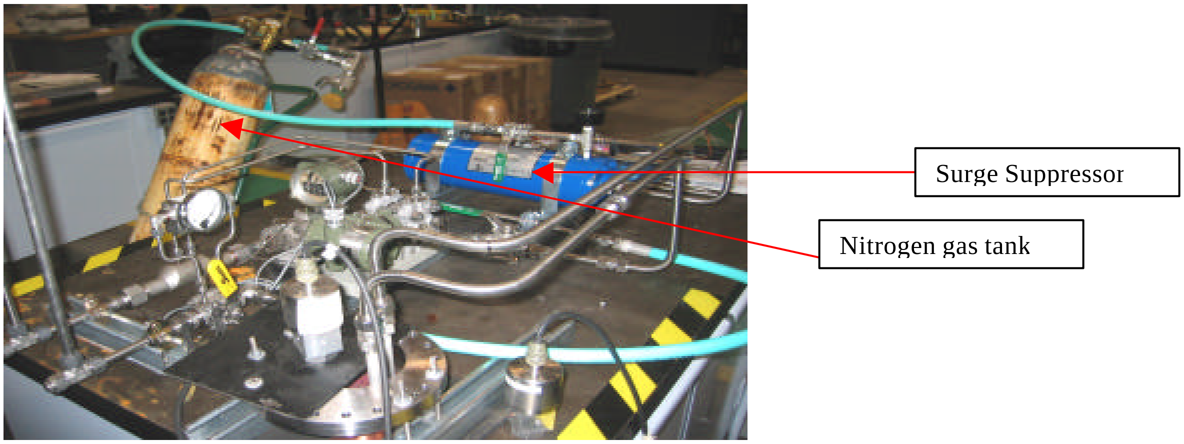

Figure 4: Surge suppressor plus balancing valve with tube connections. Water flows from the supply across the valve, through the suppressor to the absorber where the reading is taken.

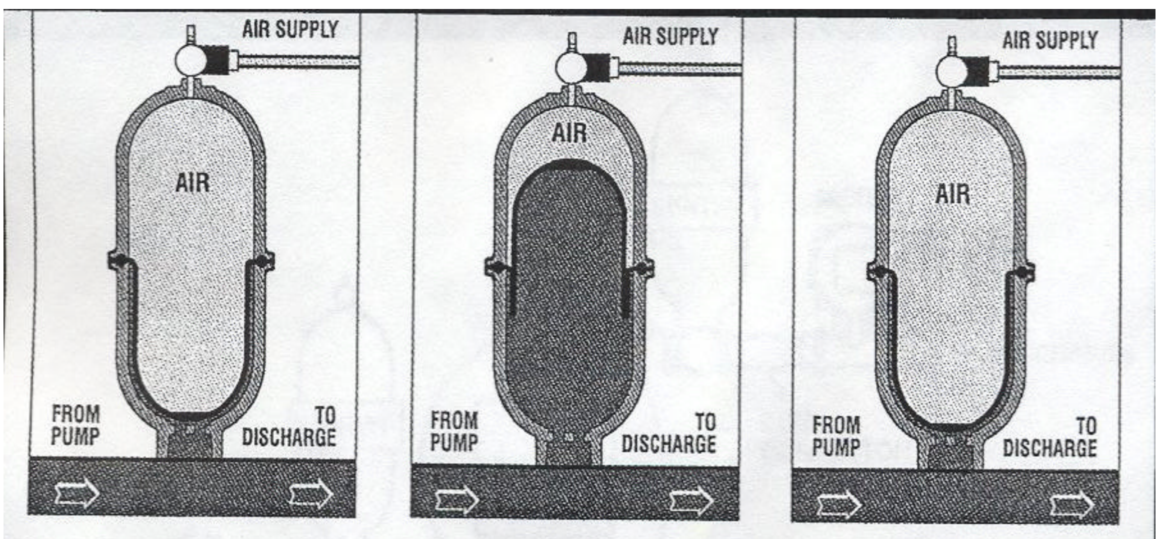

Figure 5: A general overview of how the surge suppressor functions (this is not an exact picture of the suppressor used in this experiment): (Left) Compressed nitrogen is supplied to the gas side of the suppressor (Center) Water fills the suppressor, the bladder compresses until the water pressure is balanced. Liquid pressure drops below the gas pressure. (Right) With the water pressure less than the gas pressure, the bladder is forced down, discharging the water back into the pipeline. The result is a continuous flow of water free of vibrations.

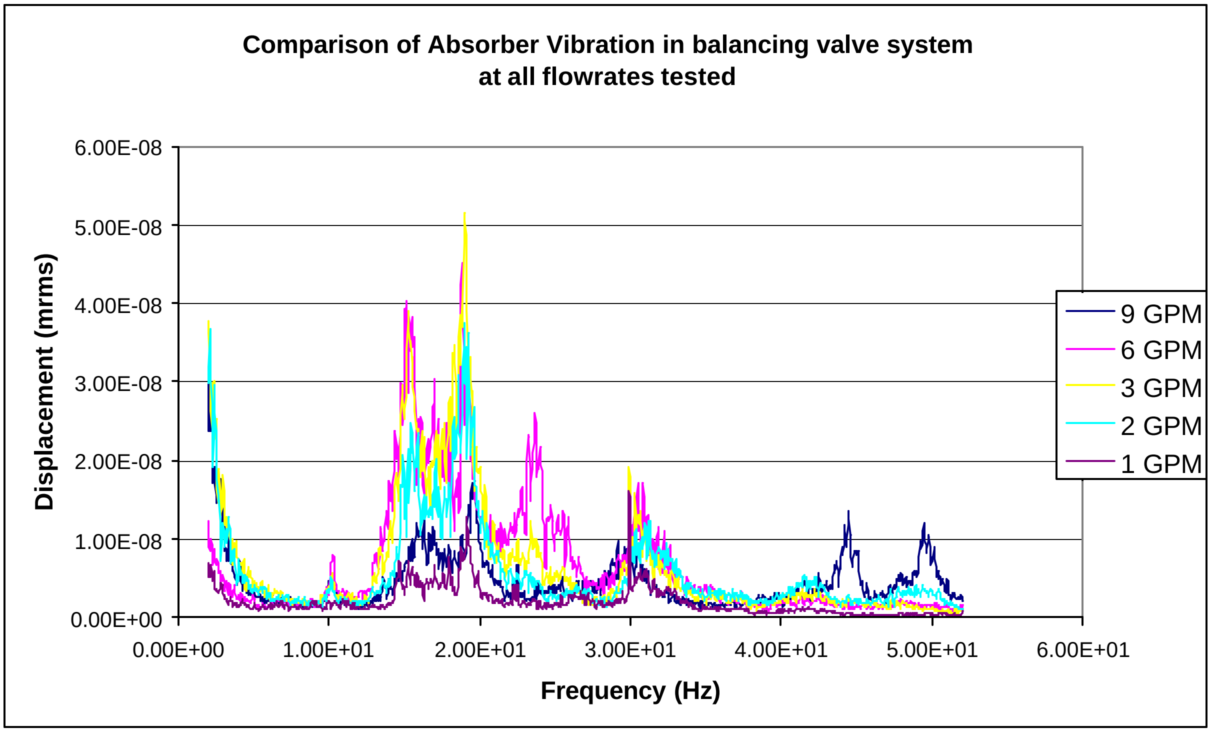

Figure 6: The amount of vibration created by the balancing valve in the system at all of the tested flow rates.

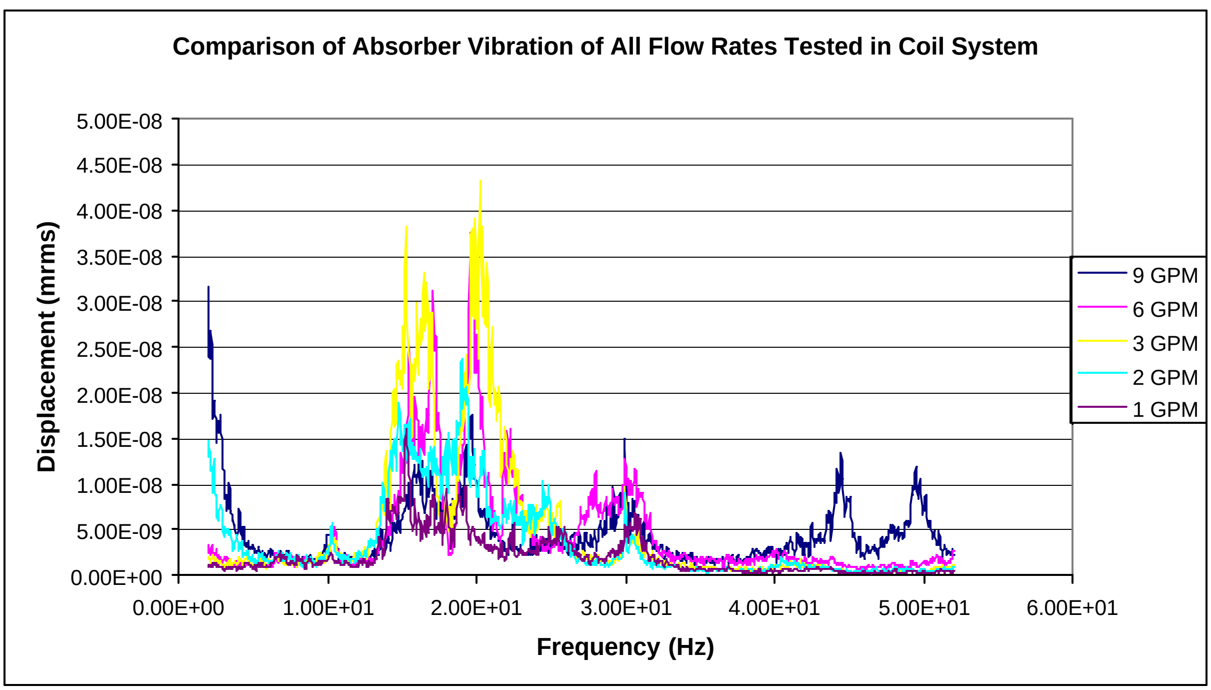

Figure 7: The amount of vibration created by the balancing coil system at all of the tested flow rates.

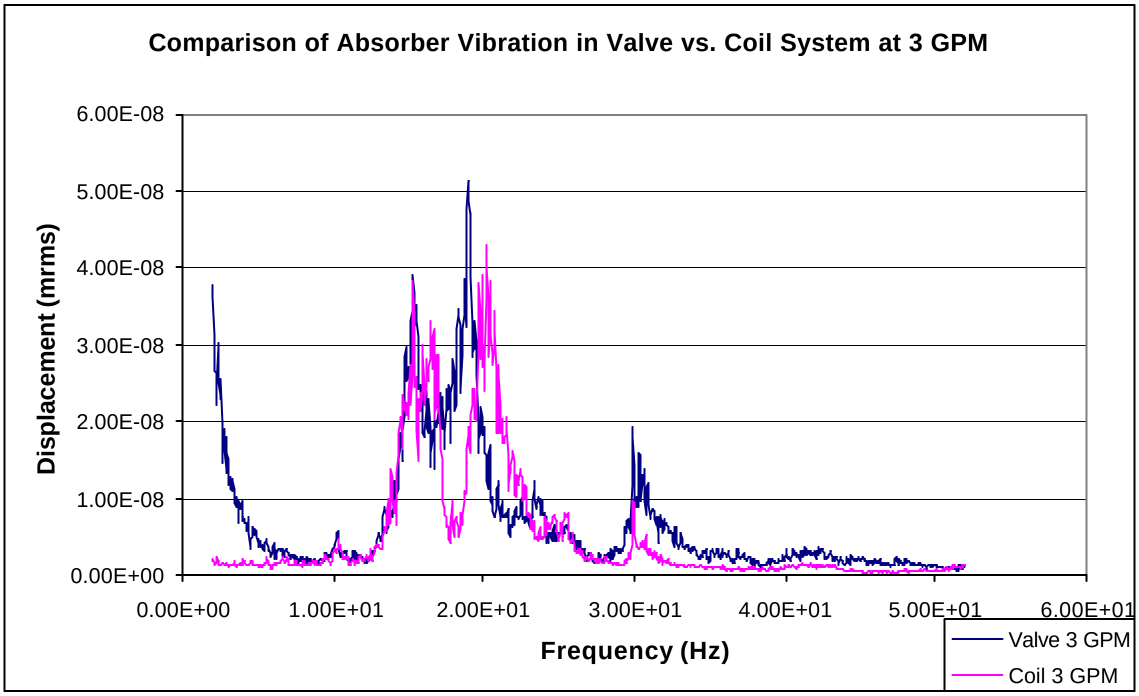

Figure 8: The difference in the amount of vibration caused by the balancing valve and balancing coil system at 3 GPM.

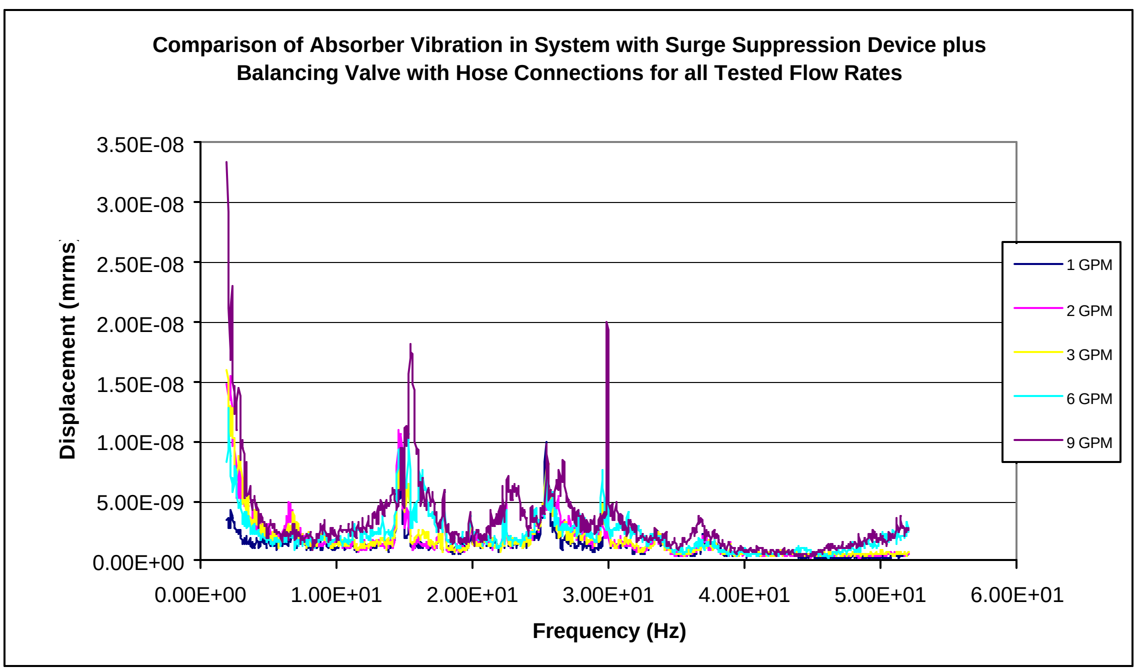

Figure 9: The amount of vibration created by the surge suppressor with hose connections system at all of the tested flow rates.

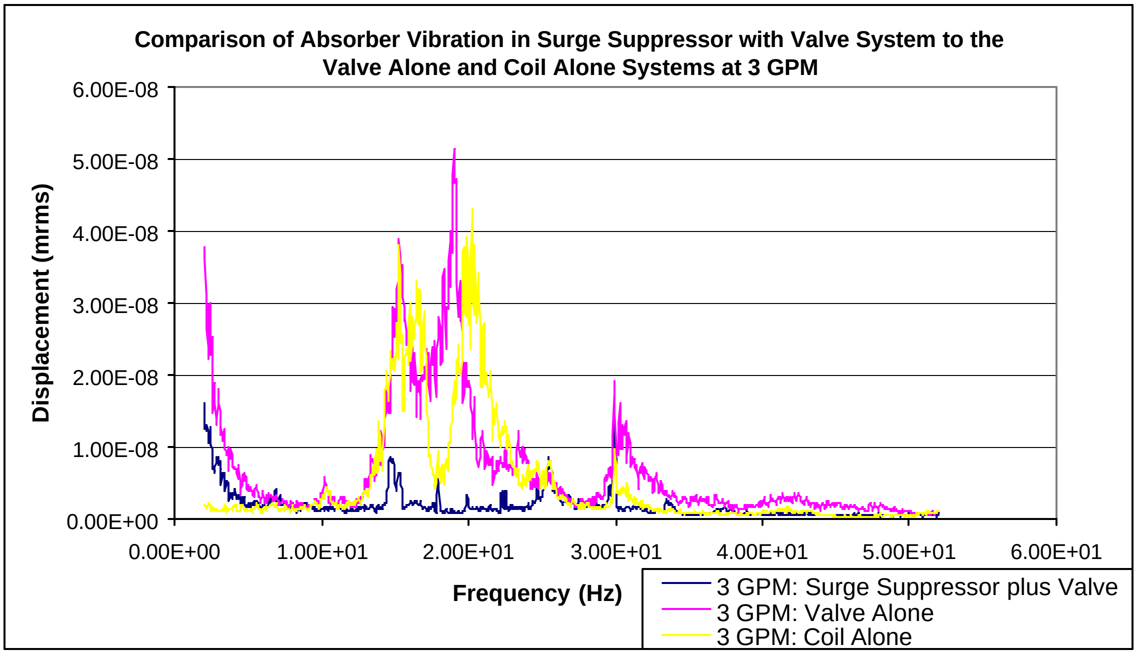

Figure 10: The difference in the amount of vibration in the three systems: the balancing valve alone system, the balancing coil alone system, and the surge suppressor plus valve with hose connections system.

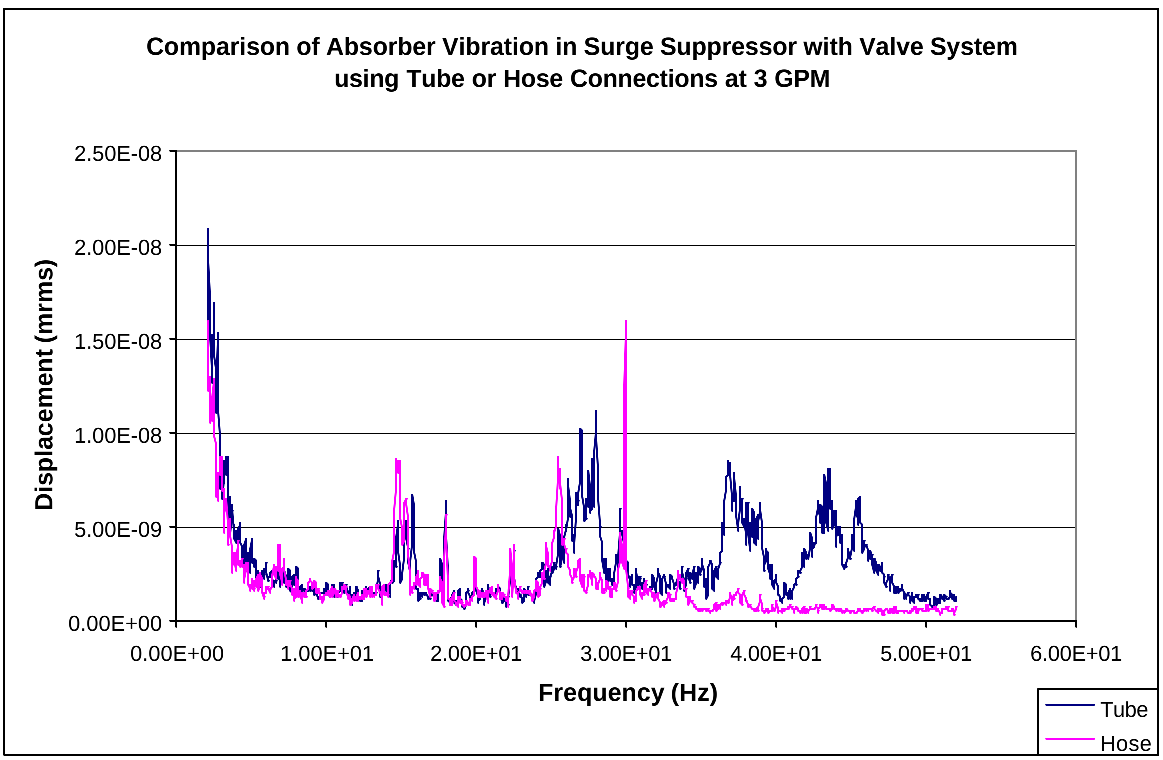

Figure 11: The effect of using tube connections in the surge suppressor system instead of hose connections.

References:

[1] Gary Cornell, “Pressure pulsation prevention,” Flow Control, March 1996.

[2] Blacoh Fluid Control, Sentry Pulsation Dampeners and Surge Suppressors, Blacoh Fluid Controls, 1997.

[3] Gary Cornell, “Controlling surge and pulsation problems,” Blacoh Fluid Controls, Inc.

[4] Gene Swetin (Private Communication), Mechanical Engineer: Argonne National Laboratory, 2003.

[5] Robert Blevins, Flow-Induced Vibration, Krieger Publishing, 2001.

[6] Hewlett Packard, HP 35670A Dynamic Signal Analyzer Product Overview, Hewlett Packard, 1997.